Linear Collider R&D

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Linear Collider R&D

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Introduction

- Fermilab is the only laboratory in the US Laboratory that is collaborating on both warm (NLC) and SRF (TESLA) linear collider technology R&D.
- Accelerator Physicists and Engineering staff from Technical Division and Accelerator Division have contributed significantly to both the Linear Collider designs.
- Fermilab ESS has played a leading role in the US site studies for the Linear Collider sites in Illinois and California.
- Fermilab Particle Physicists are working on four major detector components R&D and coordinating simulation efforts.

Accelerator Physics Studies

- The key to the success of the Linear Collider is production and transport of low emittance beam to IR.
- At the start of our accelerator physics effort we have decided to look at
  - Damping Rings for TESLA and Pre-Damping Ring for NLC
  - Emittance preservation in LINAC and alignment requirements.
  - Electron Beam Physics modeling tools

TESLA Damping Ring

- TESLA design of Linear Collider requires 2820 bunches of electrons at ~335 nsec spacing. This makes the TESLA Damping Ring rather long.

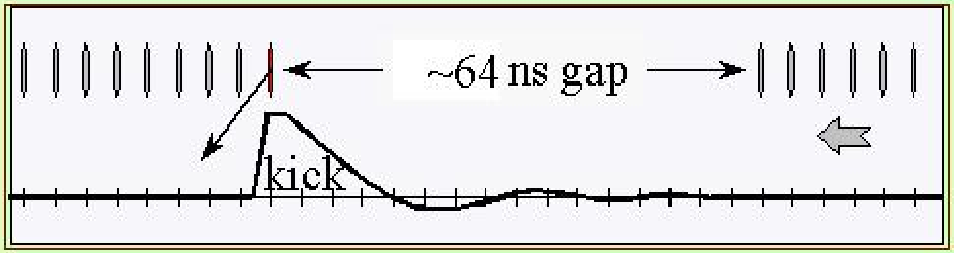
- The present design of the TESLA Damping Ring though technically sound is 17 kms long. The key limitation being faster kicker.

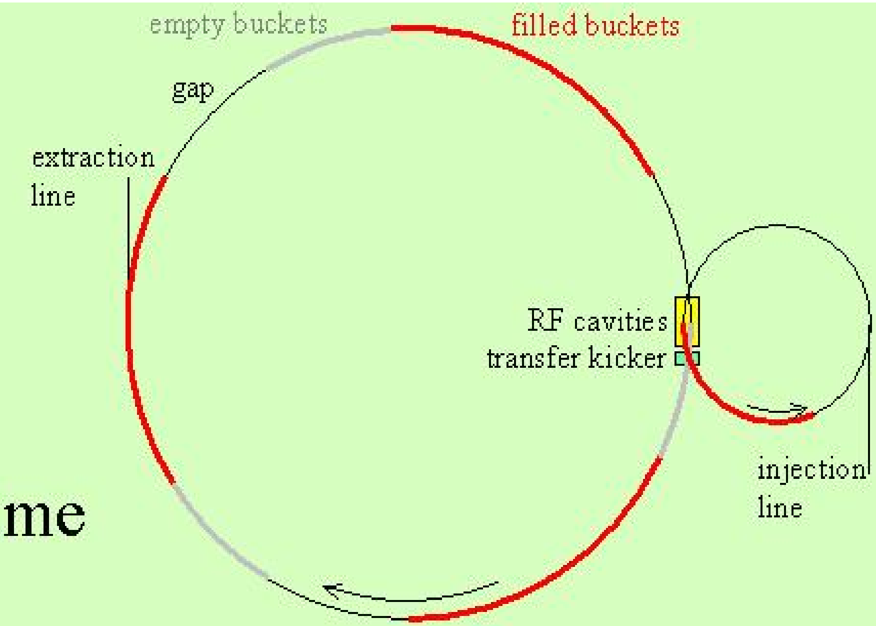
- We are investigating several ideas on a faster kicker scheme by developing a common lattice design.

- We are developing conceptual design(s) for these kickers and how to test its performance.

Damping Ring Studies

Multi-Bunch Trains with inter-train gaps

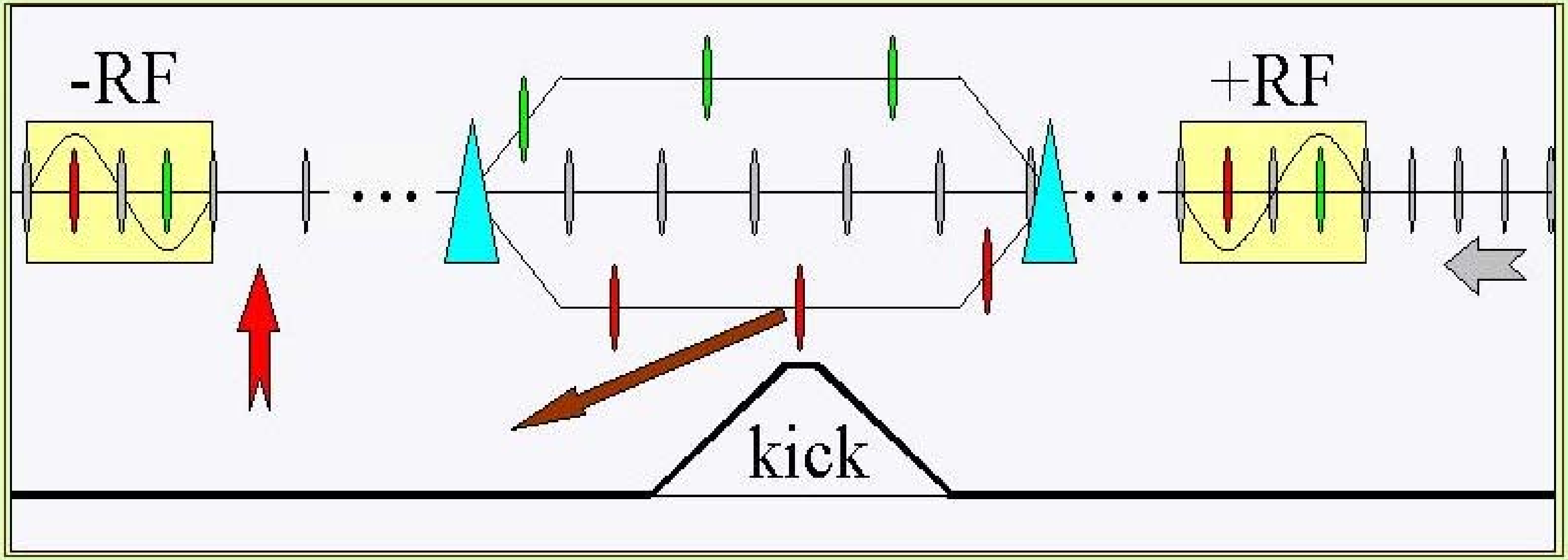




- always inject and eject the last bunch in a train
- kicker rise time < 6 ns, but fall time can be ~gap length
- beam loading maintained by ~100 m ring with shared RF system
- ~6 km ring filled by transfers of undamped trains from the ~100 m ring

J. Rogers

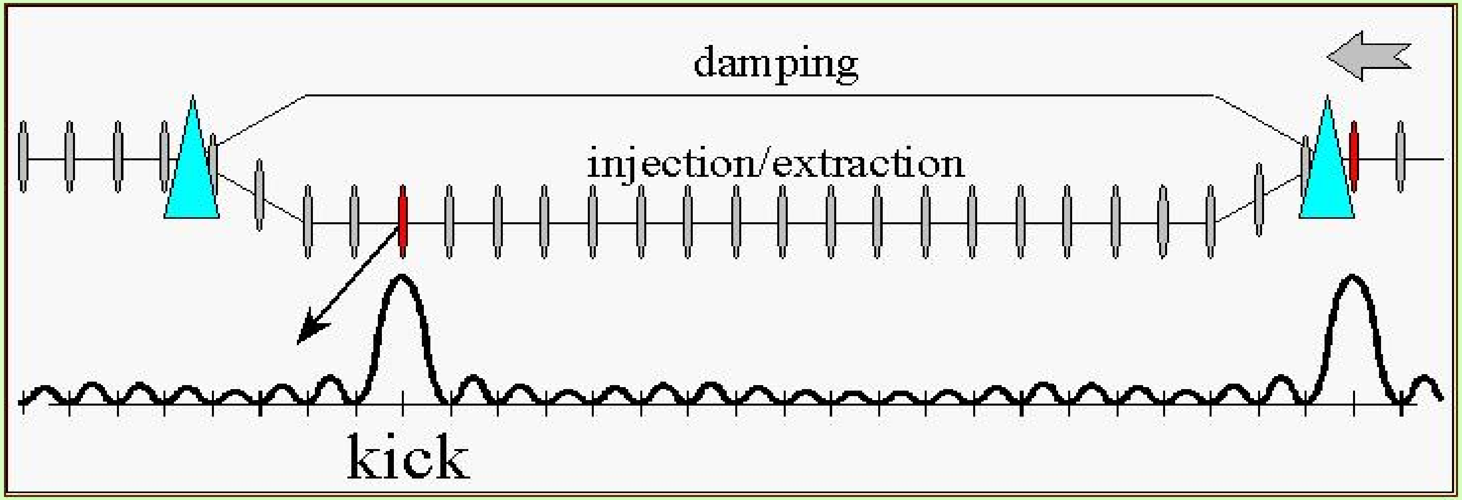
Longitudinal RF followed by Dispersive Section



- kicker rise, fall times can be 4× bunch spacing
- could be combined with #1 to accommodate longer fall-time kicker

D. Rubin

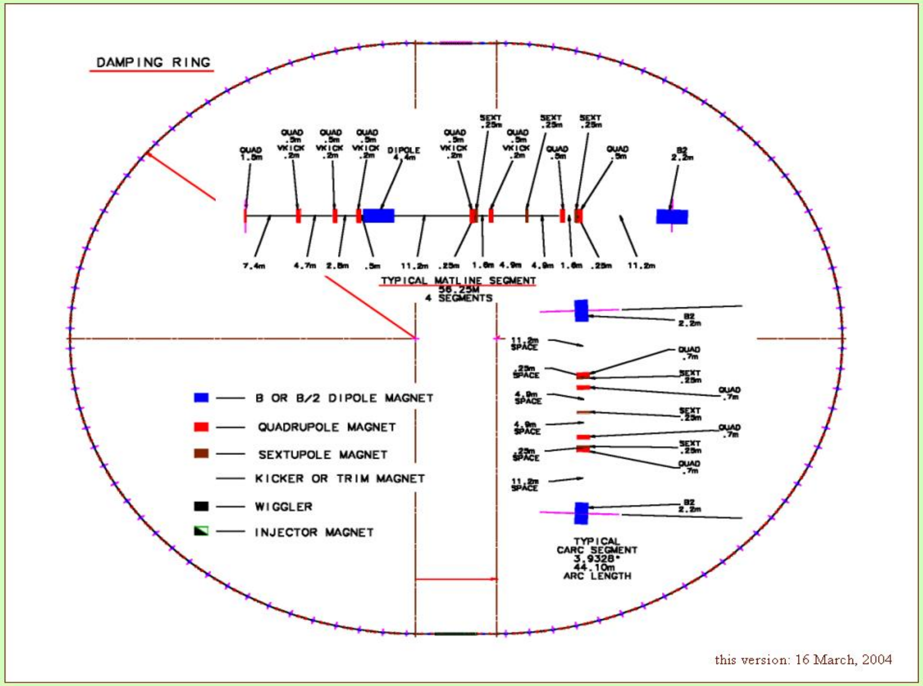
Fourier Series Kicker



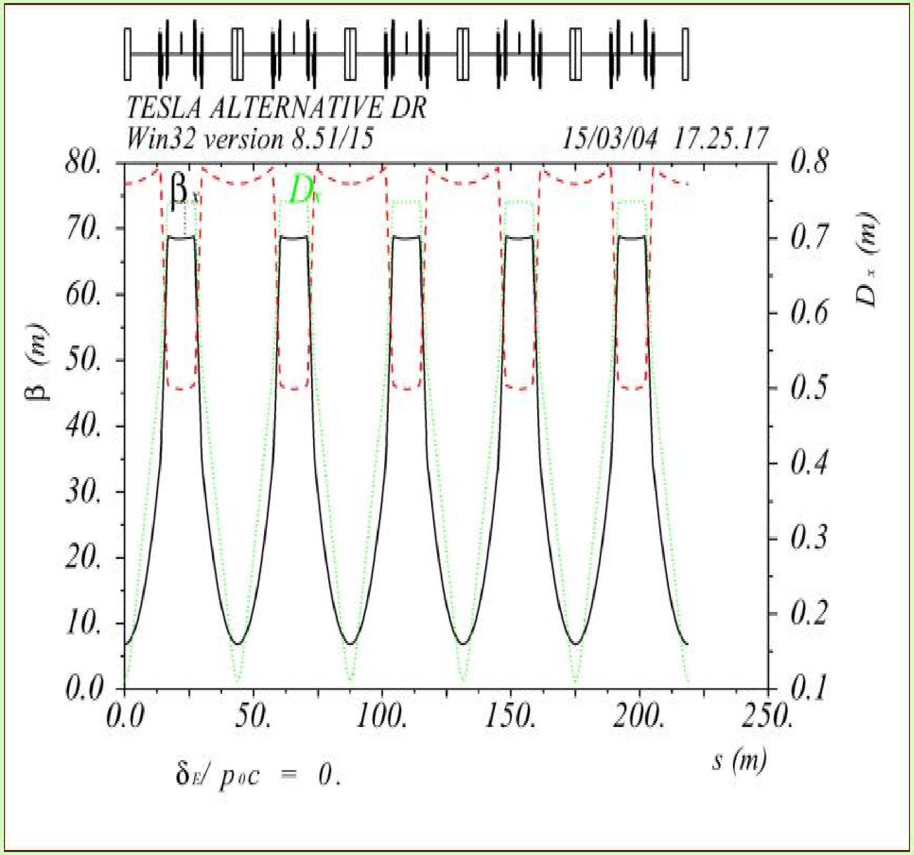
- kicker is a series of *N* transverse RF cavities tuned to frequencies which differ by ~3 MHz.
- proper adjustment of amplitudes and phases kicks one bunch while leaving the next (*N*-1) undisturbed.
- SCRF + transverse kick minimizes beam-induced fields in cavities.

G. Gollin

Damping Ring Lattice



Workshop at Fermilab: ANL, LBNL, SLAC, Cornell, DESY, FNAL…



6 kms, 6 straight sections, 25 wigglers.

Comparison of two designs

Parameter	Small ring (e^+/e^-)	Dogbone (e^+/e^-)
Energy	5 GeV	5 GeV
Circumference	6.12 km	17 km
Horizontal emittance $\gamma\epsilon_x$	2.5×10^{-6} m	8×10^{-6} m
Vertical emittance $\gamma\epsilon_y$	0.02×10^{-6} m	0.02×10^{-6} m
Transverse damping time τ_d	28 ms / 44 ms	28 ms / 50 ms
Current	444 mA	160 mA
Energy loss/turn	7.3 MeV / 4.7 MeV	21 MeV / 12 MeV
Radiated power	3.25 MW / 2.1 MW	3.2 MW / 1.8 MW
Tunes Q_x, Q_y	62.18, 28.38	72.28, 44.18
Chromaticities ξ_x, ξ_y	-112, -64	-125, -68

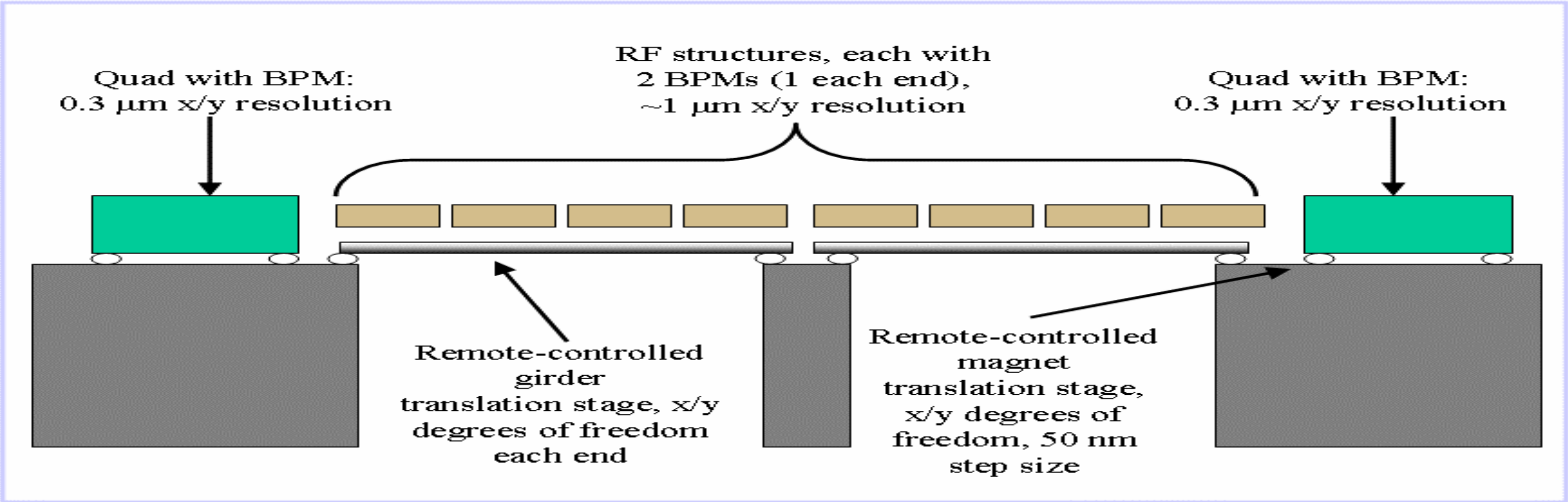
We are working on further developing these Kicker ideas.

Low Emittance Transport in Main Linac

- Damping Rings generate Low Emittance Beam this Emittance must be preserved through, Bunch Compressor, Main Linac and the Beam Delivery System.
- Emittance Budget in Main Linac (NLC) from DR extraction: 3.3% in horizontal and 50% of vertical plane.
- Emittance growth in the Linac is caused by
  - Single Bunch: Transverse wakefield resonantly drives the tail of bunch in betatron oscillation
  - Multi Bunch: Leading bunch deflects trailing bunch center.
  - Incoherent Sources: Misalignments and quadrupole errors
  - Ferbrication error (Straightness of RF structure and HOM frequency error.) reduces the effect of LR wake suppression.

Study of Beam Based Alignment

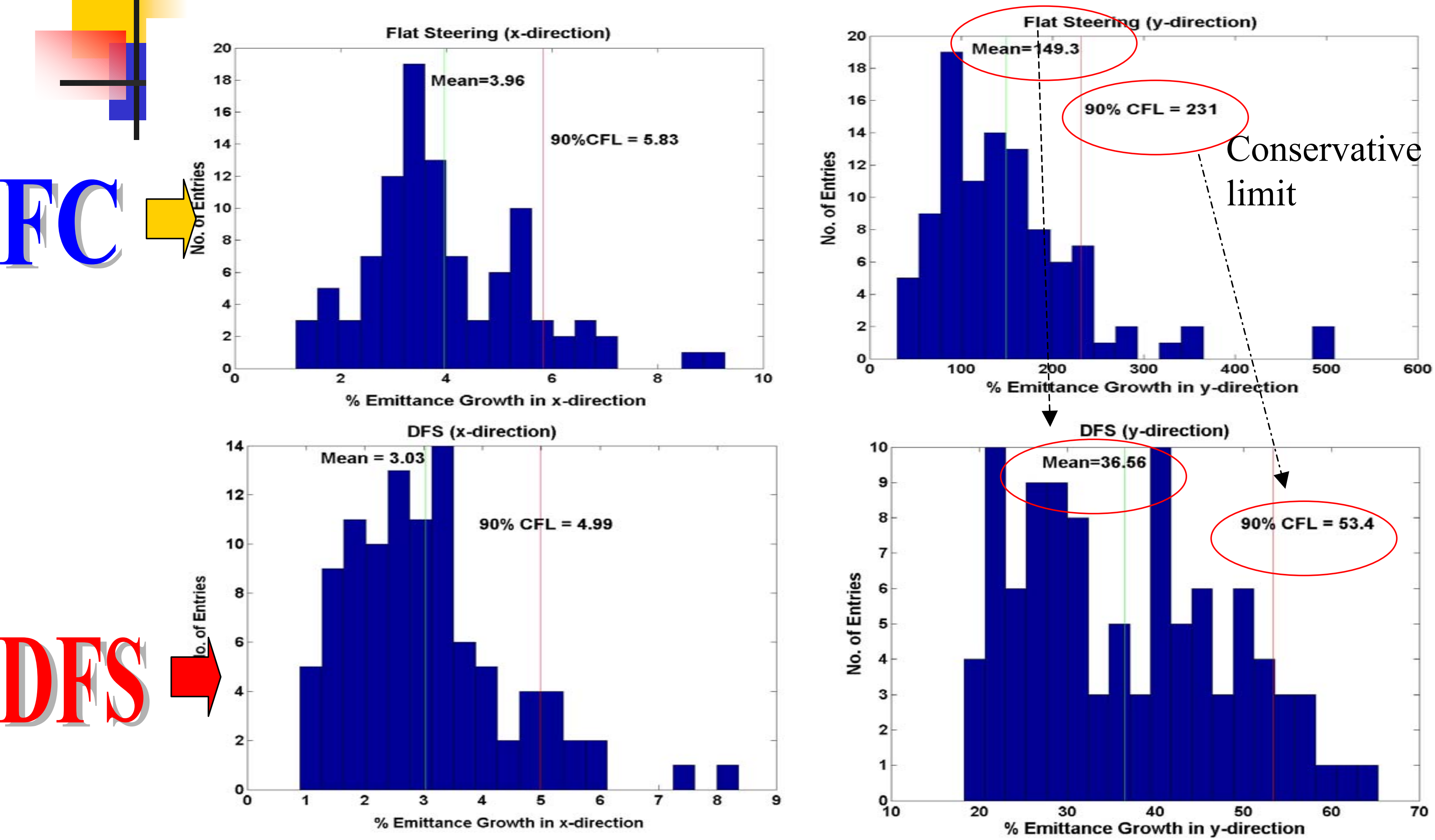
- Alignment tolerances can not be met by *ab initio* installation.
- Quads and RF structures need to be aligned with beam-based measurements.
- Two methods
  - French Curve: Read all BPMs, compute magnet moves, align RF
  - Dispersion Free Alignment



☞ Remotely controlled Translation Stages for quads and RF girders

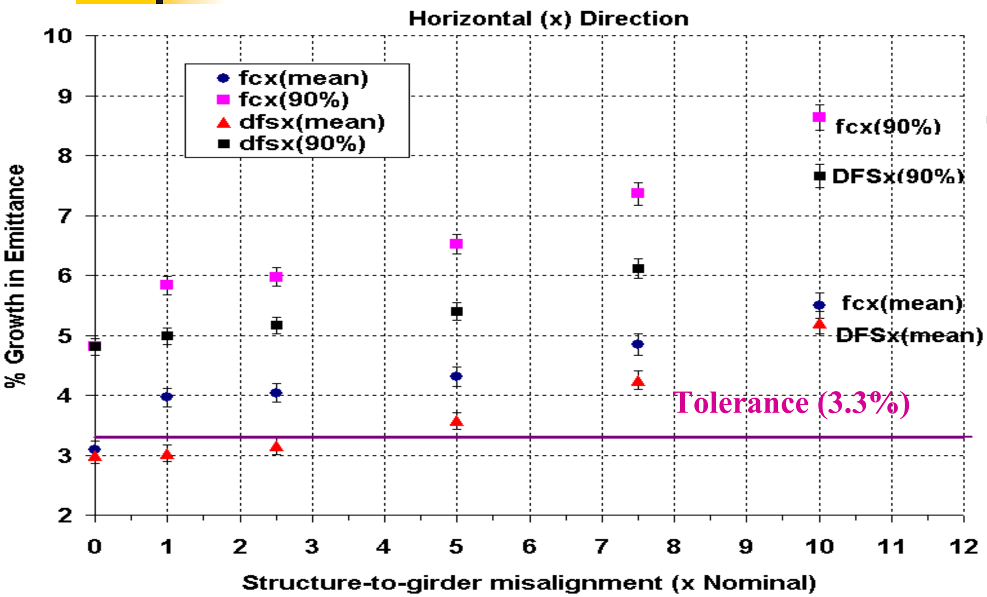
☞ High resolution BPMs in Quads and RF structures

Results

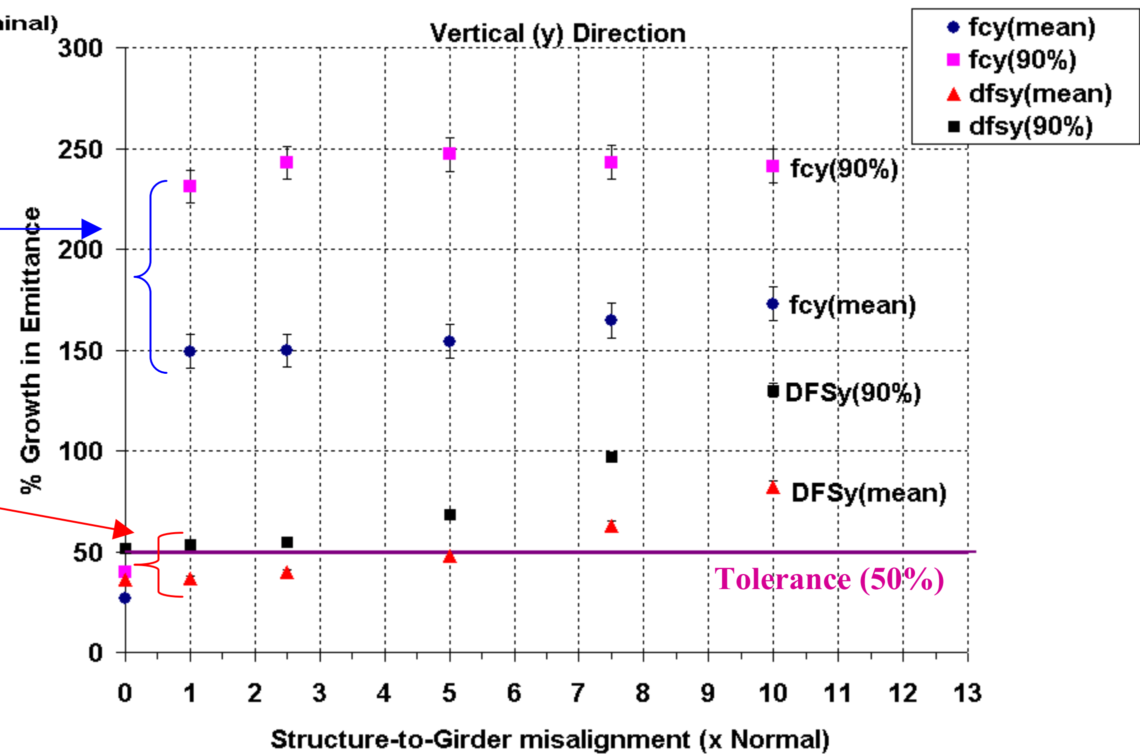


- DFS: Lower mean emittance growth than FC
- DFS is More effective in vertical plane.

Structure-to-Girder Offset

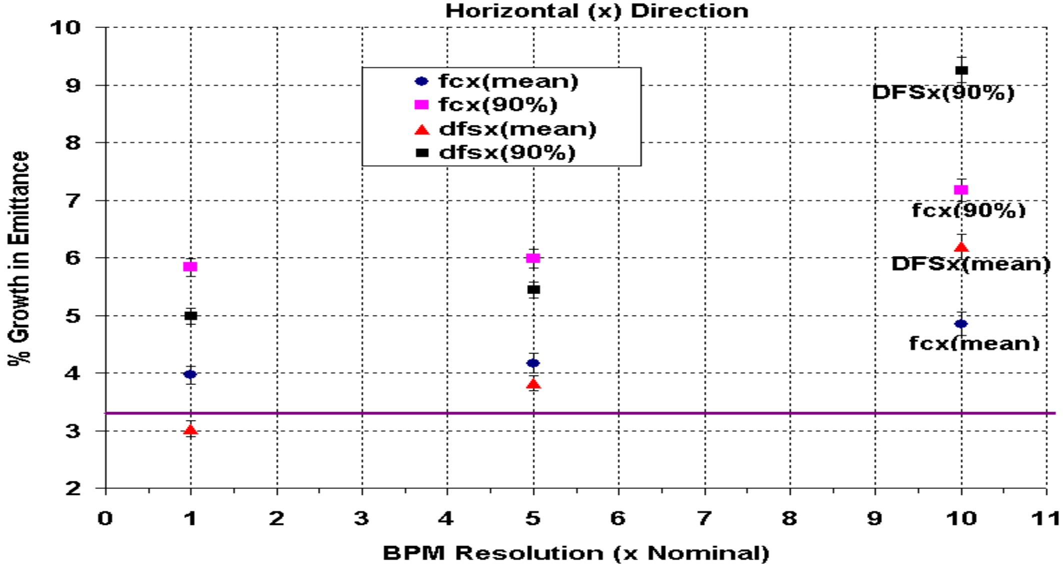


- γe_x growth in DFS and FC:
  - DFS: mean (~ x2.5 within tolerance)
  - DFS: 90% CFL can create problem
  - FC: both mean and 90% limit beyond tolerance even for nominal values.



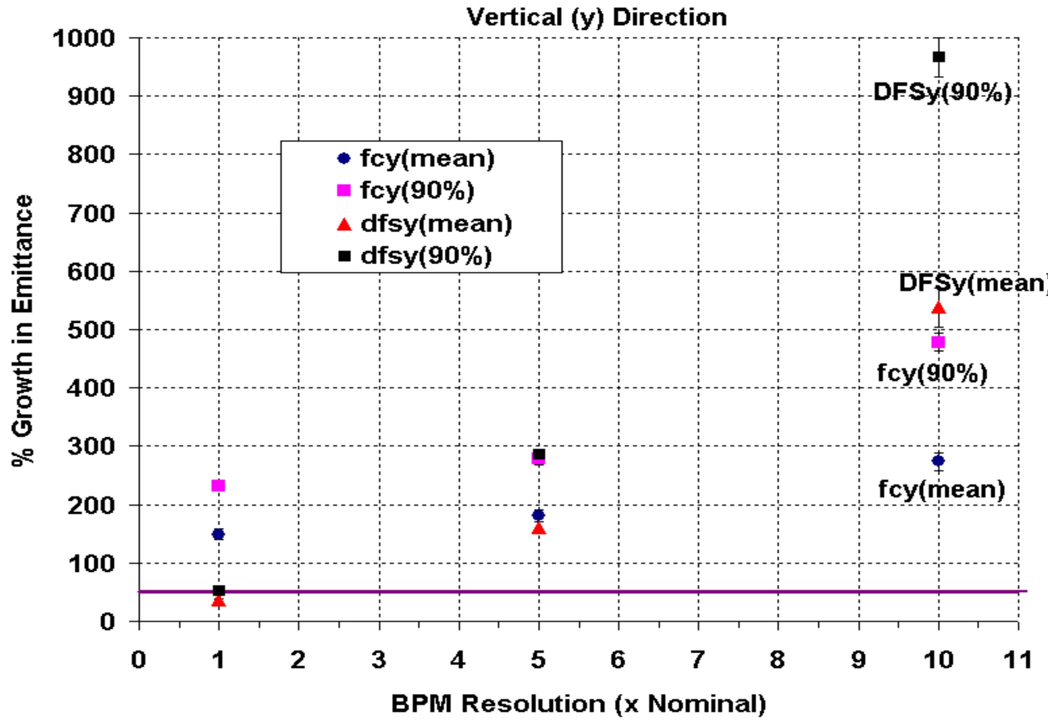
- γe_y growth in FC:
  - remains almost constant (~ x5 nominal values), but
  - much above tolerance.
- γe_y growth in DFS:
  - increases more rapidly.
  - mean within specs. (~x5 times)

BPM Resolution



- γe_y & γe_x growth in FC:
  - ☞ lesser dependence, but,
  - ☞ much above tolerance.

- γe_y & γe_x growth in DFS:
  - ☞ depends heavily on BPM resolution.
  - ☞ should remain within Nominal values.



Engineering Test Facility for LC

- At present there are Test Facilities at SLAC, KEK and DESY that are designed to do LC R&D.
- We believe that next generation of LC Engineering Test Facility is needed for a complete system test of the Linear Collider and accelerator physics.
- The scope of such a facility needs to be defined.
- To be most effective this proposal should be developed by the U.S./International linear collider collaboration(s).
- Fermilab is taking a leading in organizing the ETF effort. We assume that the emerging design would go to the Global Design Organization as a proposal.

Thoughts on the Scope of ETF

- It must be done with International collaboration.
- It should have the capability to do perform beam studies.
- ETF could be 1% demonstration machine for the technology chosen by ITRP in the final machine configuration.
- It could have an Injector, Linac (5 GeV), Damping Ring, post damping ring Linac (~0.5 GeV-5.0 GeV)
- It could be a development facility for the Instrumentation, controls etc needed for the LC.
- It could be a development facility for one of a kind device.
- It could be used for industrialization/ later testing of the major component.

NLC R&D Overview

- X-Band RF Structure Design and Fabrication
  - Review of cell table of SLAC disk design, construction with local industry, QC of the RF disk
  - Frequency tuning of the single disk (if needed).
  - Fabrication of 60 cm RF structure
  - Frequency tuning of the assembled RF Structure
- RF Design work
  - Design of the Fermilab wave guide coupler for FXB, FXC and FXD Structures
  - FXD HOM extraction design and analysis
  - Design of Fermilab Structure FXE

RF Structure Factory

RF Quality Control Clean Room (Class 3000)

- Brazed structures, no diffusion bonding

A Structure during Bead-Pull Measurements & Tuning

- Disks & Couplers are precision machined, no diamond turning (industrial vendors)

Warm LC RF Structure Disks

– **FXB:** 60 cm. Long, high phase advance (150 deg.), traveling wave structures (aka H60VG3, no slots) were produced. (FXB001-006)

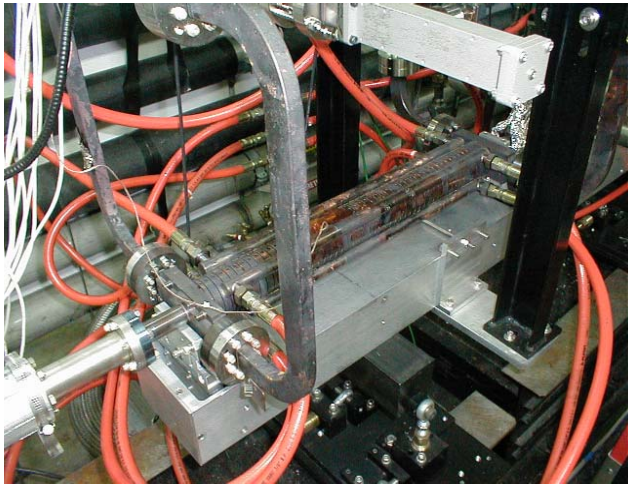
–**FXC:** 60 cm. long, 61 mm o.d. cells; 150 degree phase advance; 3% group velocity; slotted cells with .17 a/λ; fully brazed construction w/o H_2; Fermilab Wave guide (FWG) I/O couplers and matching cells, no HOM extraction, 4 tuning holes instead of the 2 in FXB structures. (FXC001-005)

•FXD: 60 cm. long, 61 mm o.d. cells; 150 degree phase advance; 4% group velocity; tapered design with slotted cells and .17 a/λ ; fully brazed construction w/o H_2; FWG I/O couplers; I/O HOM extraction; twofold interleaving design feature. (FXD001-006)

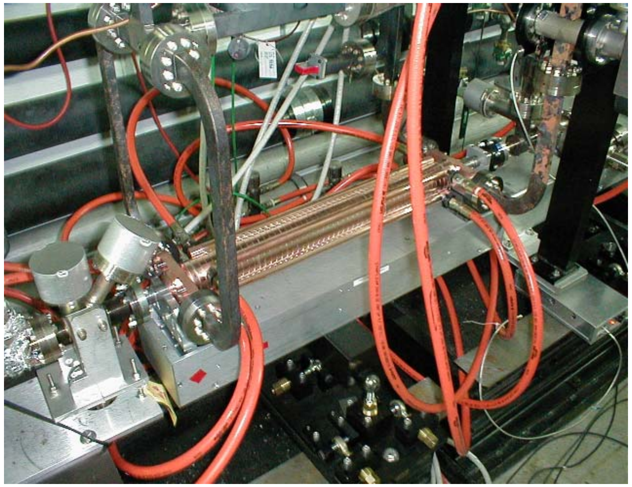
- FXE: Fully Fermilab Designed

FX-band Structures at NLCTA

- Four structures currently operating at NLCTA were fabricated by Fermilab.
- FXB-006 is the first structure built by anyone to achieve NLC specification for gradient and breakdown rate (<0.1 breakdown/hour @ 60 Hz, 400 nsec, 65MV/m)



FXB-006

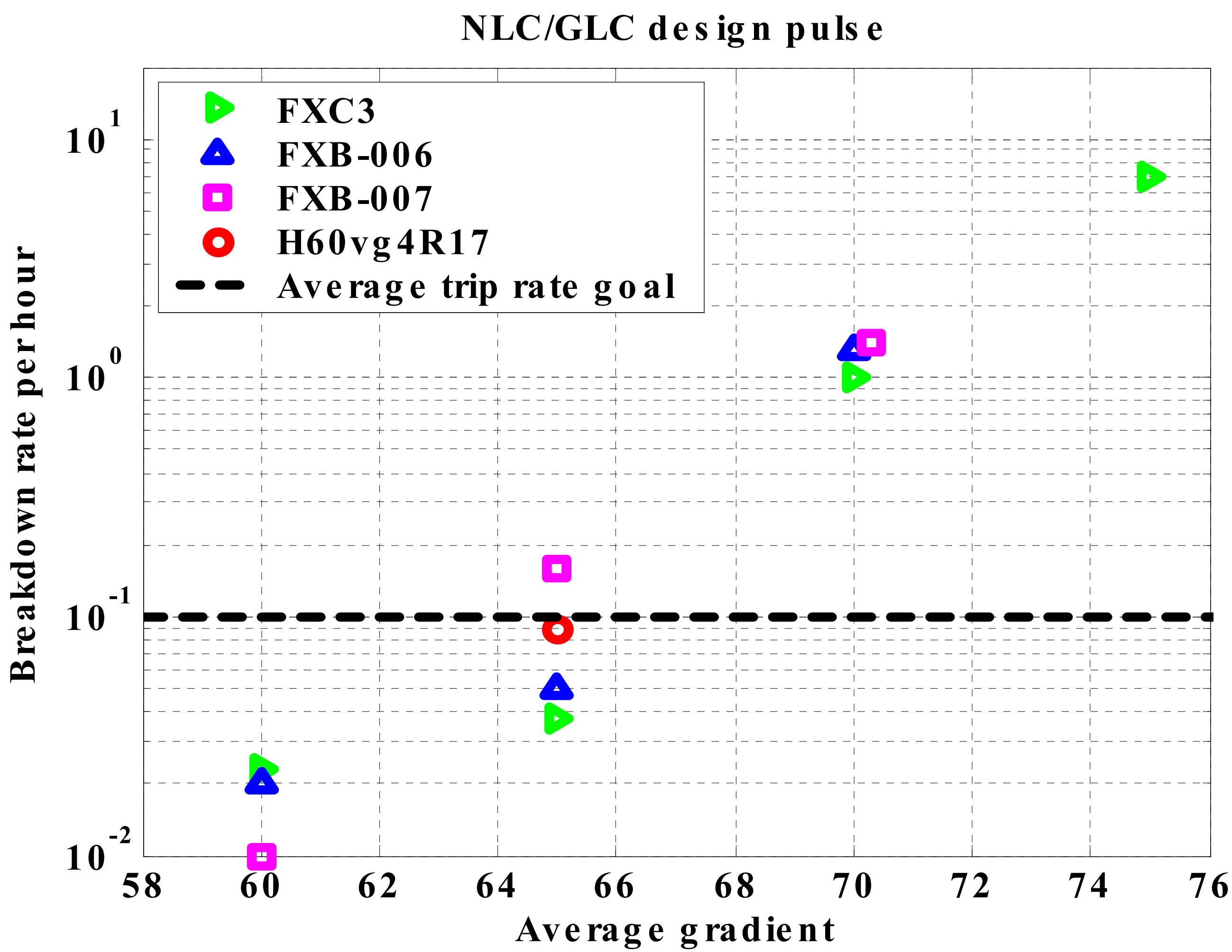


FXC-001

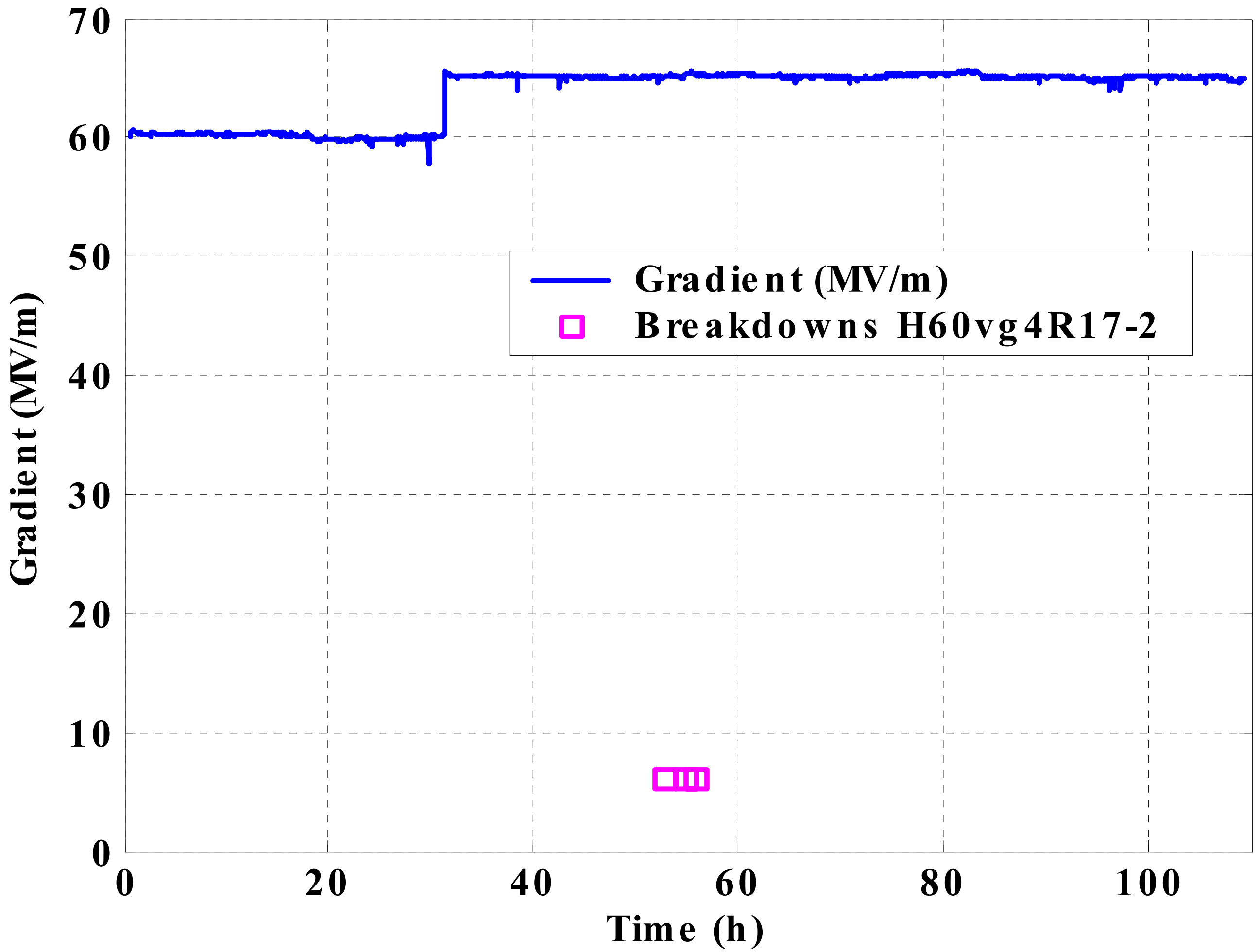
- FXC003 has also met the NLC design goals.

Processing results from the 4 latest NLC/GLC prototype structures

3 out of 4 exceed breakdown rate requirements at 65 MV/m

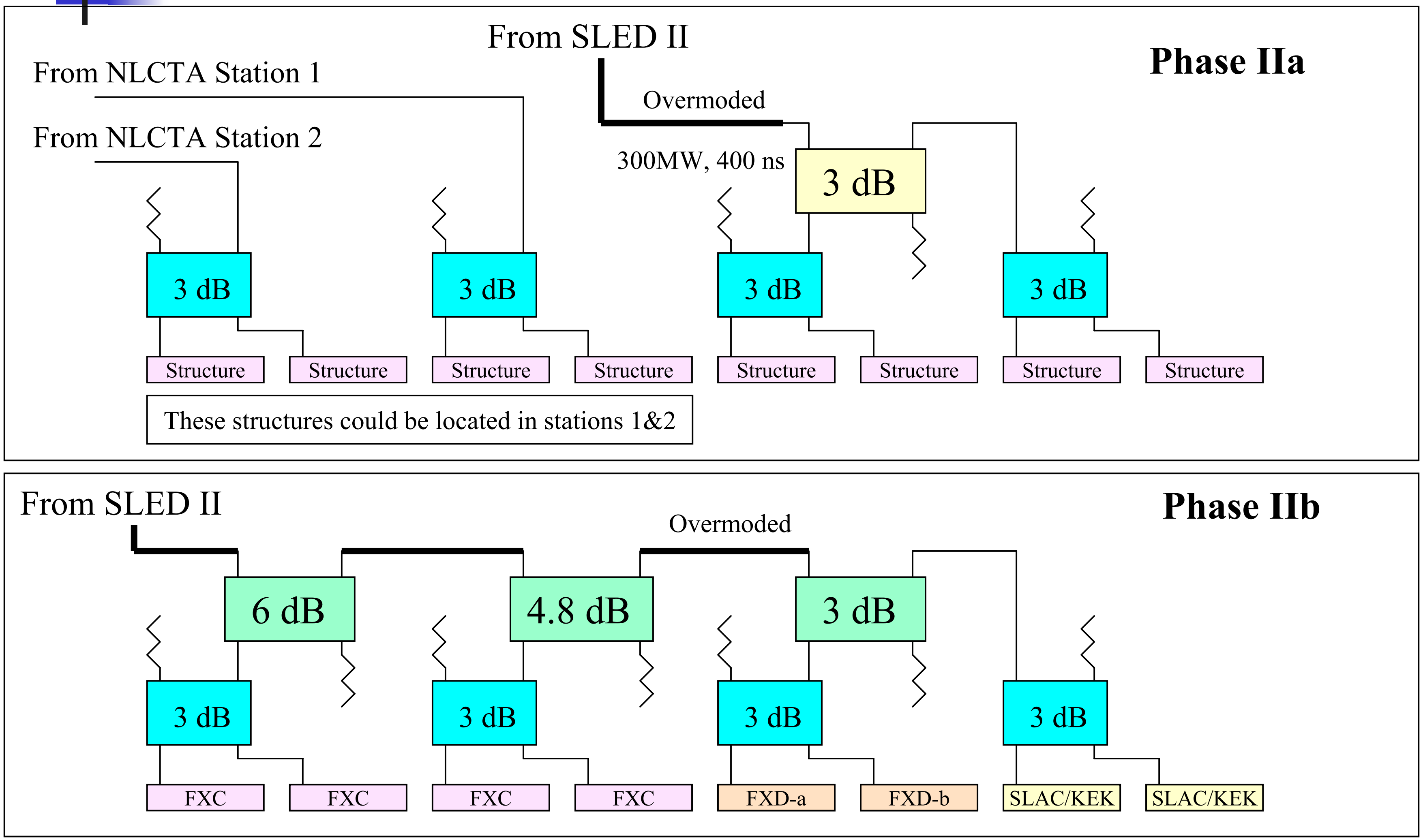


FXC-003 golden run at 65 MV/m with the NLC/GLC design pulse



Breakdown rate : 0.038 /h (3 trips in 80h at 65 MV/m)

Eight Pack Phase 2: Power Handling



Strongback Production

Dummy Structure being test fitted
On an NLCTA-style "Strongback"

FXB-002 Mounted on NLCTA-style "Strongback"

- We produced nine structure supporting systems known as "strongbacks"(six for NLCTA use at SLAC, and three for use in girder development at FNAL)

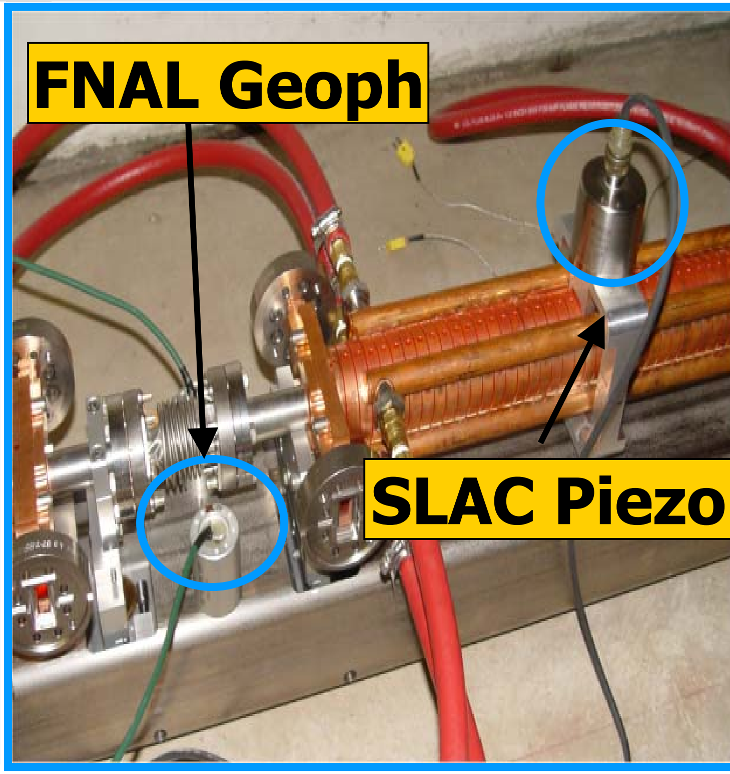
Vibration studies @ MP8

Studies:

- Effect of cooling water on structures stability
- Comparison of Al and SS strongbacks
- Effect of vacuum on vibration transmission
- Transmission of vibration to quads (PM EM)

Study on more realistic supports

- Effect of movers on structure stability
- Adding more constrains: waveguides



In Collaboration with SLAC and Northwestern University we are setting up a ground motion experiment in the NUMI/MINOS tunnel.

Overview of SCRF activities

- Linear Collider R&D
  - For TESLA we built modulators and electron guns for TTF at DESY (AD) and designed vertical test dewars and cryostats
  - The A0 photo-injector at FNAL is very similar to TTF and uses TESLA acceleration cavities
  - We also are designing and building a 3.9 GHz 3rd harmonic cavity. The purpose is to diminish the beam energy spread so that the electron pulse length can be made very short via a magnetic chicane
- CKM
  - FNAL has been doing R&D to build 3.9 GHz transverse kick cavities for an experiment proposed at FNAL that needs an RF separated K beam
- Proton Driver
  - FNAL has a design study in progress for an intense Proton Source based upon a 8-GeV SC linac

FNAL SCRF Technical Capabilities

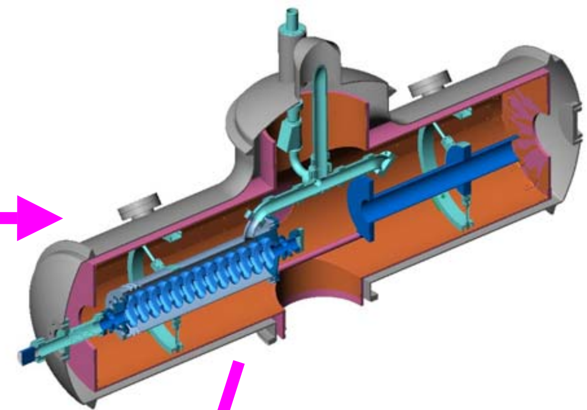
- Both in the FNAL Accelerator Division (AD) and Technical Division (TD) have significant design capabilities useful for SCRF work
  - Cryogenic Engineering and Design
    - Engineers with experience on big cryogenic systems (Tevatron)
    - Designed 1.8 K cryostats for LHC IR quadropoles in TD
    - Test them at 1.8 in FNAL Magnet Test Facility
  - RF Engineering and Design
    - RF design engineers
    - Modern FR Engineering Software and design tools
    - Computing equipment
    - Improved modeling/analysis techniques
    - (eg working on the design of xband NLC structures and couplers)
- We also have been collaborating with ANL and DESY on SRF Cavity Surface Treatment Facility and plan to expand our collaborations with other labs and universities

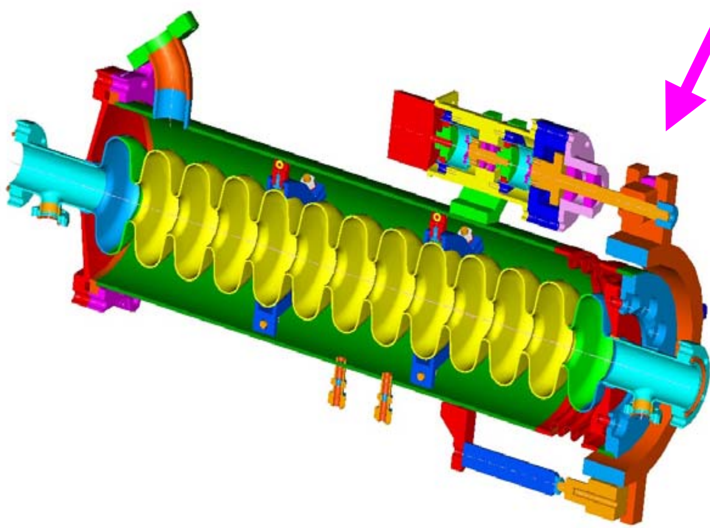
SCRF R&D

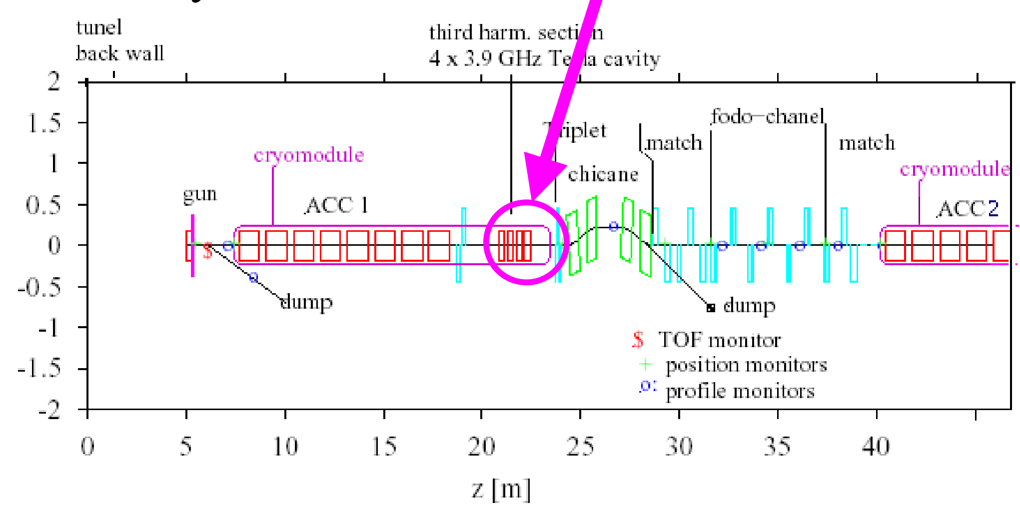
- FNAL is currently doing some Superconducting RF R&D that can benefit to the TESLA proposal (3-d harmonic system development)
- TD RF group is working on SCRF R&D for two FNAL projects that build SCRF capabilities relevant to a LC if the technology decision is for a cold machine
  - **CKM:** Collaboration with BD. Goal is to provide SC RF cavities (transverse kick mode) to be used to generate a separated charged K beam for the CKM experiment
  - **A0 3rd Harmonic cavity:** Goal is to provide a 3.9 GHz accelerating cavity to reduce longitudinal energy spread of high current electron pulses from the A0 photo-injector. (Note: TESLA would like us to build one of these for TTF-II also so there continues to be collaboration in this area)

SCRF R&D

- Building our capabilities for the future
  - Develop and build elements of a SRF module fabrication and test infrastructure
  - Design and build a prototype of a 3.9 GHz accelerating cavity for the Photo-Injector Test Stand
  - Develop a microphonics compensation system

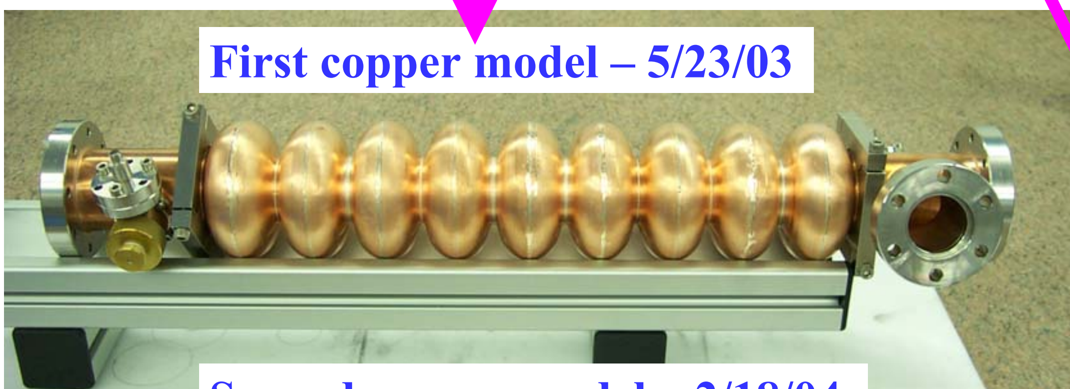




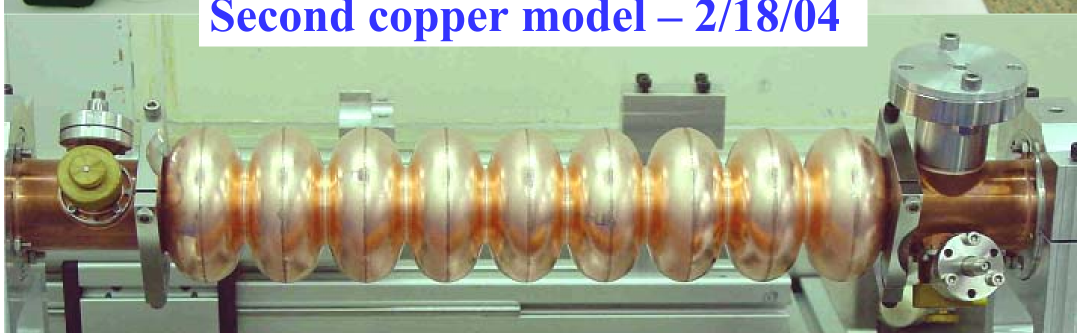


3.9 GHz accelerating cavity

- 9-cell cavity and helium tank design and fabrication
- HOM coupler design and fabrication
- Cell and cavity design and prototyping



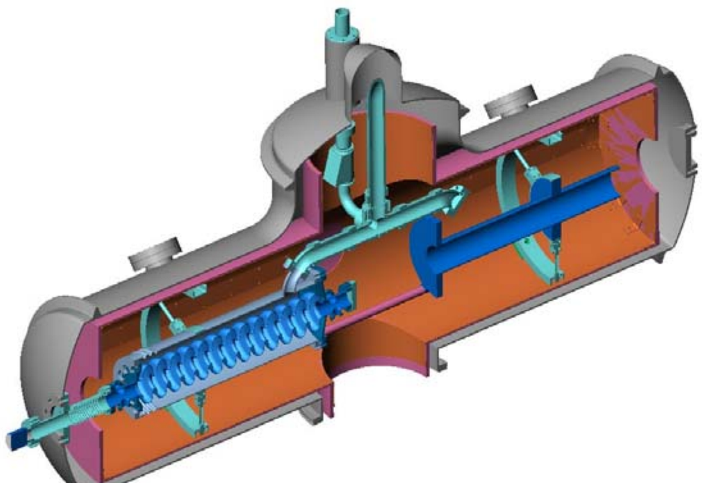
First copper model – 5/23/03

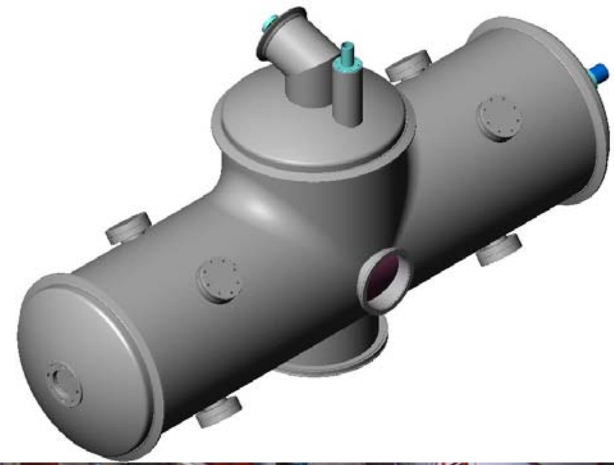


Second copper model – 2/18/04

SCRF Module Fabrication

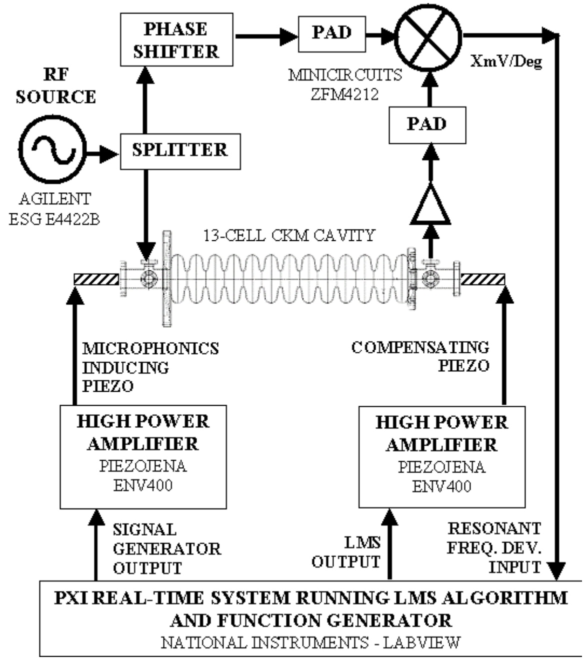
Cryostat for CKM cavity testing

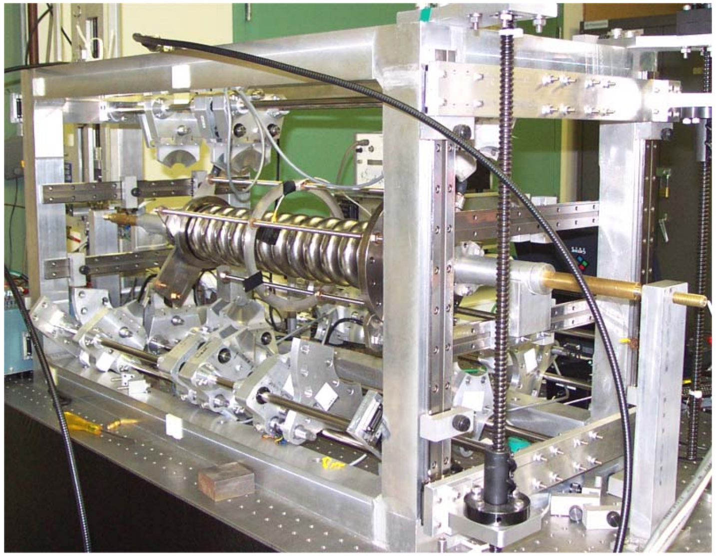


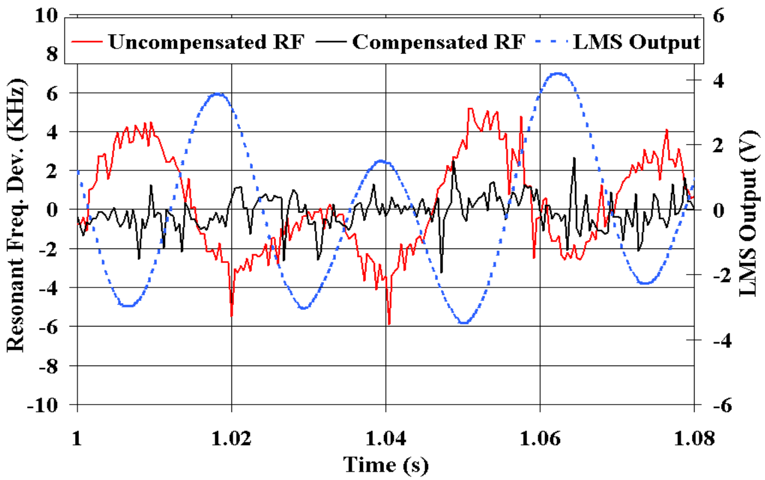


SCRF Module Fabrication

Microphonics Detuning Compensation



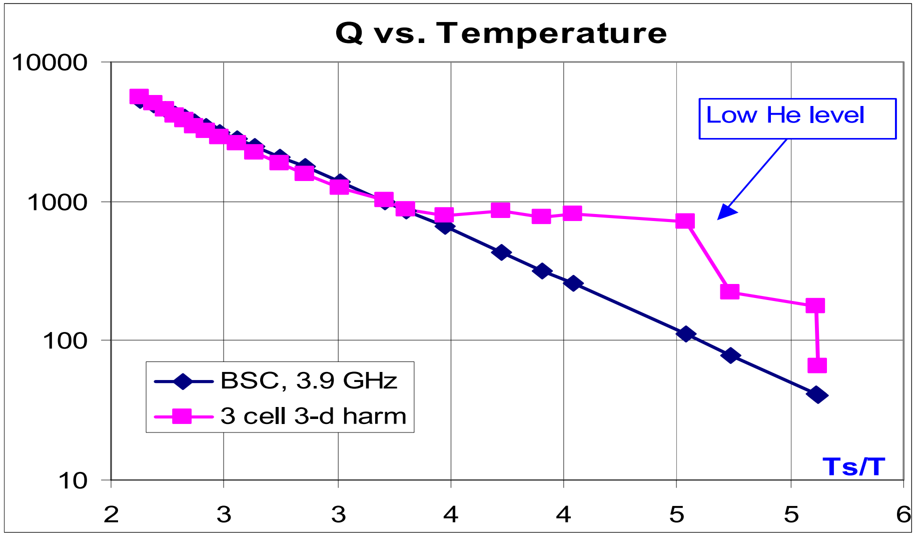


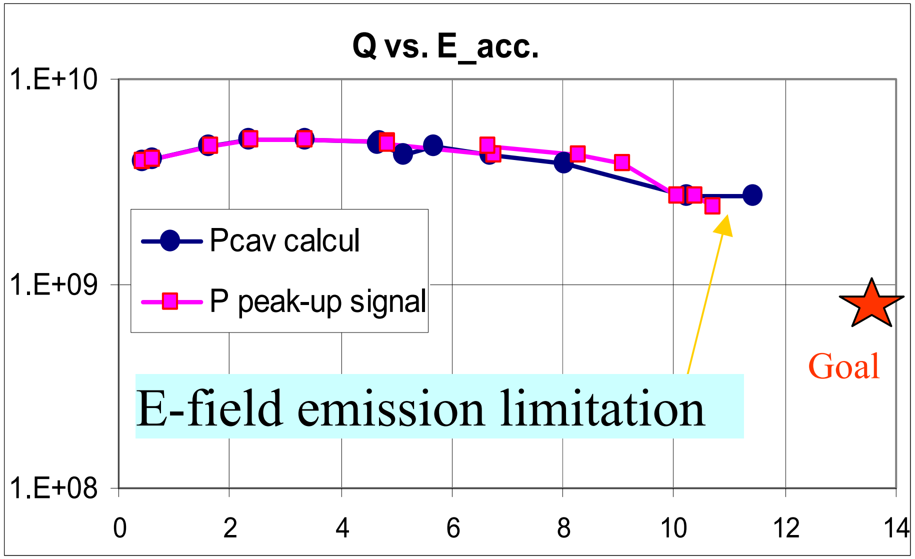


Automatic compensation with adaptive feedforward control method demonstrated in a 13-cell CKM cavity at room temperature.

Cold Test of the 3.9GHz 3-cell cavity in the Vertical Cryostat

Tested after 140 μm BCP, heat treatment and HPR

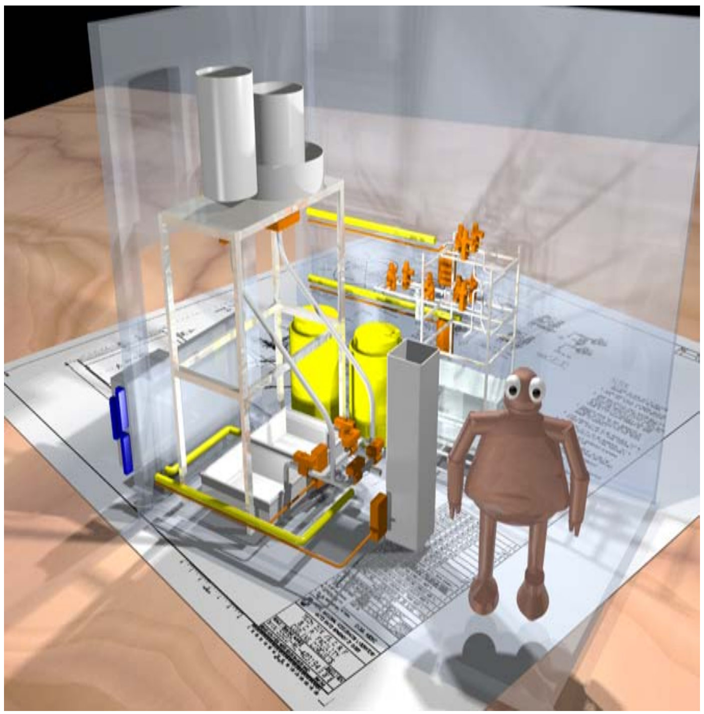




Surface treatment facility

Process Compartment Design

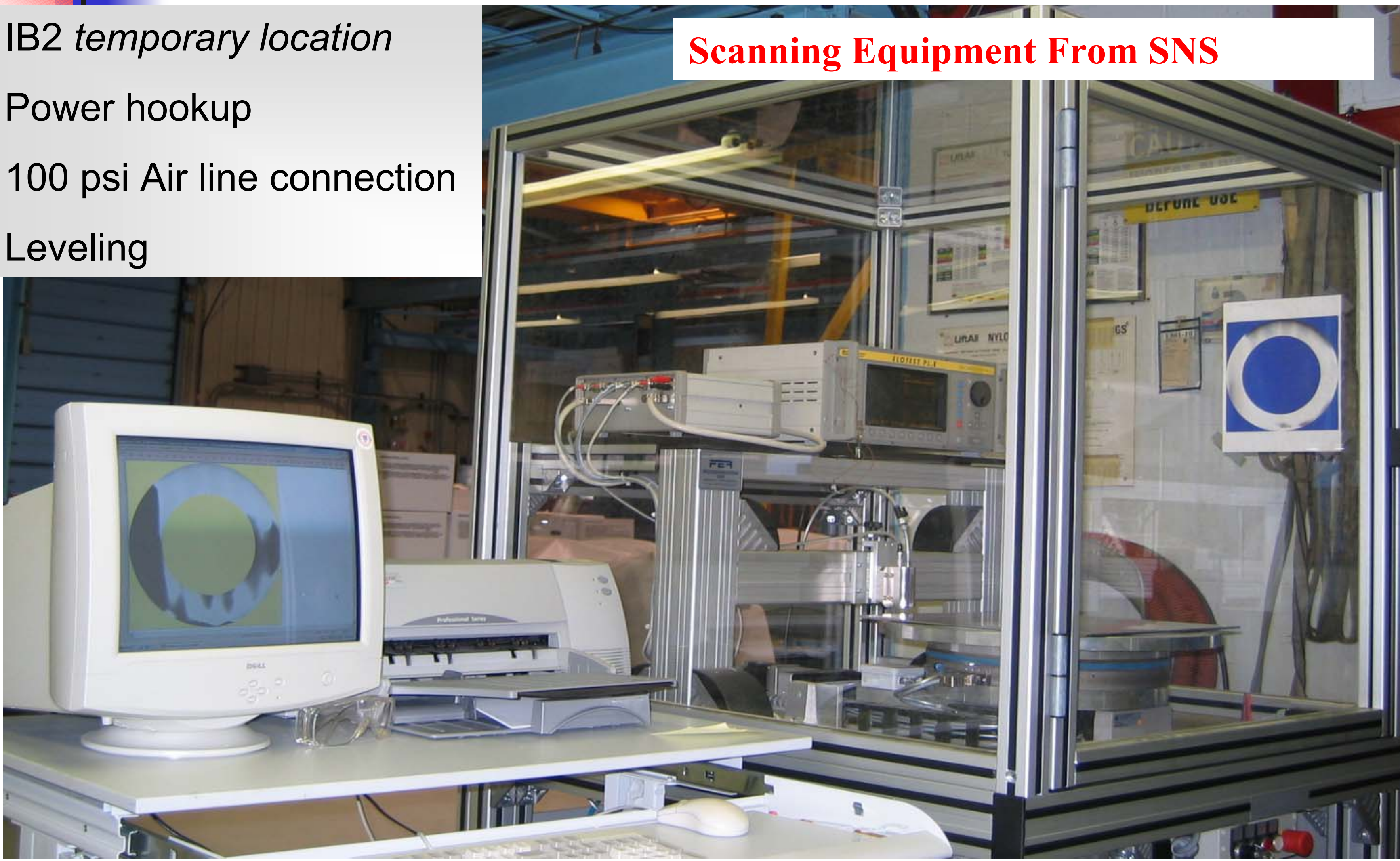
Mockup @ FNAL TD MDL



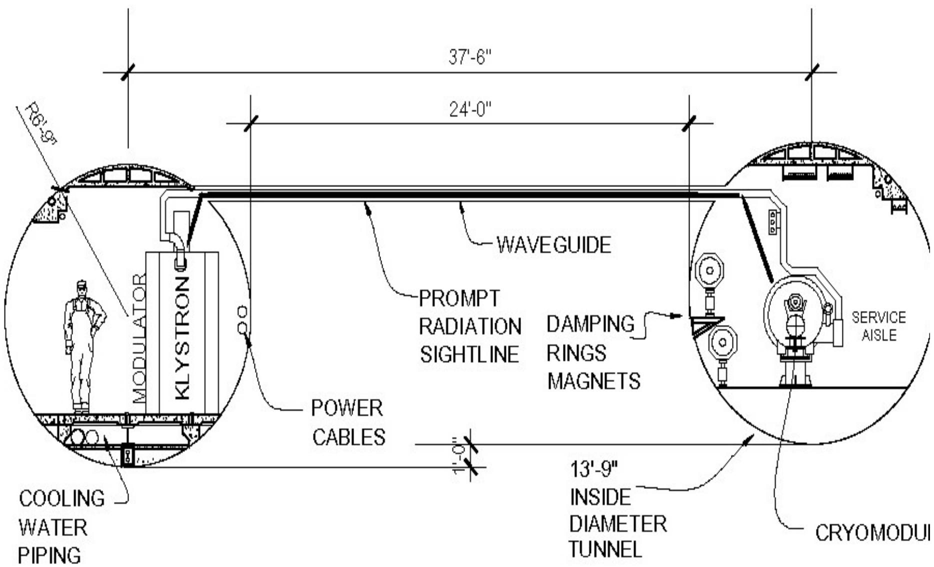
Eddy Current Scanner

- IB2 *temporary location*
- Power hookup
- 100 psi Air line connection
- Leveling

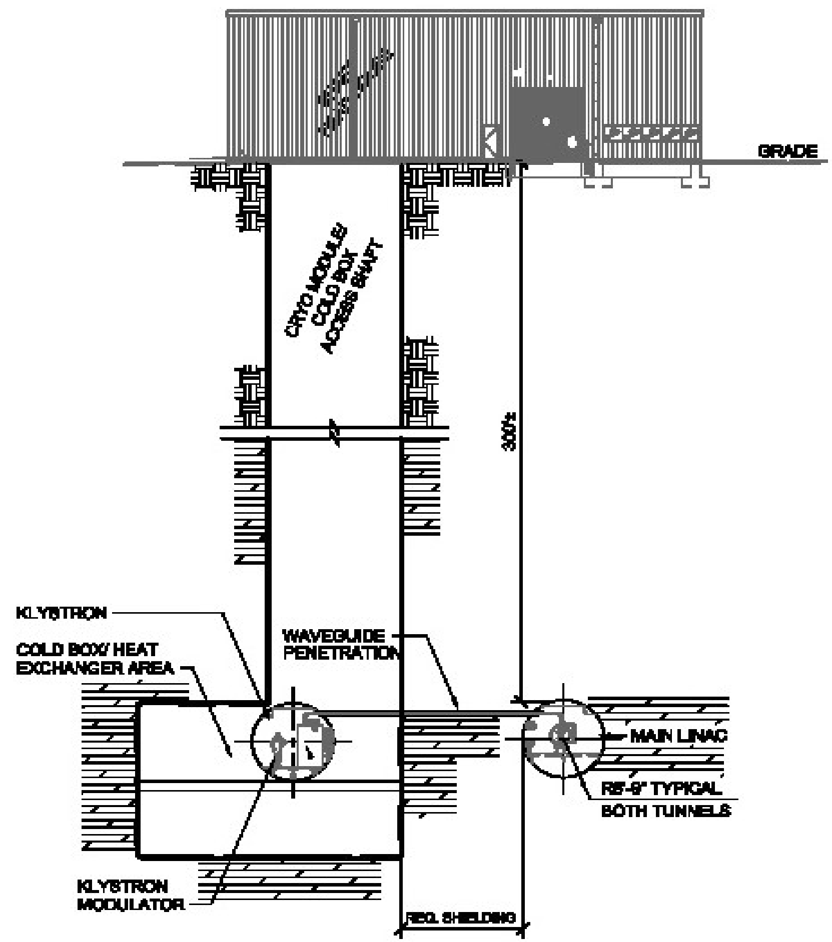
Scanning Equipment From SNS



Linear Collider Site Studies



MAIN LINAC TYPICAL SECTION 2 X



TWO TUNNEL SOLUTION

Fermilab and LC Technology Decision

- We are also developing detector collaboration with in US and except that Fermilab will play a major role in such a collaboration.
    - Fermilab has considerable experience in building large detectors, Silicon, Tracking Chambers, Muon & Calorimeter.
    - Computing Infrastructure and GRID
- Illinois and Fermilab is an ideal choice for the Linear Collider site.
- We are working with local universities and ANL to bid to host Linear Collider in Illinois after the technology selection.

Summary

- Fermilab has made significant contributions to both the NLC and TESLA R&D.
- Fermilab is aligning itself to be a significant player in the Linear Collider
    - We will continue and expand our efforts in the accelerator, detector and IL site studies.
    - We are increasing our effort in the accelerator physics in Main Linac and Damping Ring.
    - We are proposing to build a LC ETF (warm or cold) at Fermilab to be in line with technology decision with U.S. and International linear collider collaborations.
- We are increasing Fermilab and Illinois presence within the LC collaboration(s).
- We are taking an active role in US and International efforts on LC.